Acta Palaeontologica Polonica
Vol. 31, No. 3—4 pp. 253—275 Warszawa, 1986

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THE RUGOSE CORAL FAUNAS OF THE CARBONIFEROUS/PERMIAN BOUNDARY INTERVAL

FEDOROWSKI, J.: The rugose coral faunas of the Carboniferous/Permian boundary interval. Acta Palaeont. Polonica, 31, 3—4, 253—275, 1986 (issued 1987).

Analysis of the rugose coral fauna of the Carboniferous/Permian transition strata is discussed, with special emphasis on corals from the Pseudoschwagerina Zone. Two distinct realms: the Tethys Realm and the Cordillera-Arctic-Uralian Realm were developed in the Carboniferous-Permian time. Recently introduced taxonomic, biostratigraphic and paleogeographic data and interpretations are evaluated in terms of their global and regional value. It is postulated that corals have some importance as a supplementary group for establishing the lower limit of the Permian System.

Key words: Rugosa, Carboniferous/Permo boundary, paleogeography.

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INTRODUCTION

The following introductory synthesis of the Carboniferous/Permo boundary phase of the rugose coral evolution is based on data from earlier, well-documented papers and from new, detailed studies of Upper Carboniferous and/or Permian coral faunas. It also incorporates general considerations on the coral faunas themselves, and on the tectogenesis of various regions, mainly the mountains of the North American Cordillera. Unfortunately, the number of areas with the Carboniferous/Permian passage beds developed in the coralliferous facies is limited. Also, the research data concerning the rugose coral faunas of several of those areas are inadequate. Thus, the remarks that follow are based only on the few regions with well-exposed successions and fairly well-known coral faunas, and some of the less well known regions have been omitted.

Regional and intercontinental correlations, based on corals alone, are not yet possible at the species level. There are genera, however, which are important intercontinental biostratigraphic indicators, and may also be helpful for paleogeographic reconctructions.

An abbreviated version of this paper was read at the 27-th International Geological Congress in Moscov, 1984.

Acknowledgements. — I am indebted to Drs. E. W. Bamber, Geological Survey of Canada, Calgary, Alberta, and W. J. Sando, U.S. Geological Survey, Washington, D.C. for correcting my English and commenting on the manuscript.

PREVIOUS STUDIES

Syntheses of Permo-Carboniferous coral paleogeography have evolved, during recent years towards the recognition of geotectonic reconstructions as a basis for the more specific considerations. Few of the paleogeographical reconstructions made during the early seventies (e.g. Minato and Kato 1970; Hill 1973) did not adopt any part of the continental drift theory, although some early attempts were made (Hill 1970; Rowett 1972, 1975) in relating that theory to coral distribution and development. Nevertheless Hill (1981) accepted several of the traditional paleogeographic maps based on the Recent positions of the continents. Also, Dubatolov and Vassiljuk (1980: 528) maintained that there is no significant difference between traditional reconstructions and those based on maps incorporating continental drift. Those authors mentioned only that "it is easier to explain a number of small facts in the coral distribution in terms of continental drift." However, the number of paleogeographic reconstructions based on the continental drift theory continue to increase (Rowett 1972, 1975, 1977; Fedorowski 1977, 1980; Stevens 1982, 1983; Stevens and Rycerski 1984; Rodriguez 1984; Rodriguez, Sando and Kullmann, in press) although only some Permo-Carboniferous syntheses are mentioned in this paper. Stevens (1982, 1983) used coral studies as main basis for geotectonic syntheses, and Stevens and Rycerski (1984) found corals of potential value for accurate paleogeographic and plate tectonic reconstructions. They also traced global phylogeny and relationships of some Permo-Carboniferous corals. However, it is unclear to me why colonial corals, on which the syntheses are exclusively based, "show greater endemism than any other group of marine late Paleozoic organisms known (Stevens 1983: 603). Stevens cited colonial rugose coral genera, whose distribution from southern Ural Mts possibly to Peru contradicts the definition of endemism. Also, there are no undisputable data presented that demonstrate a lesser development of endemism of solitary rugose corals. The value of the results is decreased by the absence of solitary coral data from Stevens' (1983) study of the endemism coefficients of individual regions.

Also, Stevens' (1983) generalizations concerning the hypothetical position of the so-called "area of Pseudopavonidae" and the migration routes of the disjuncted carbonate platforms of that area towards North American as well as the Asiatic limits of the Paleopacific are unsupported. On te contrary, even considering the coral fauna alone, it is readily apparent that the Asiatic terranes (?) characterized by Pseudopavonidae and *Parawentzelella* were also inhabited by several other taxa not present in the more sparsely populated Cordilleran terranes. This would not have taken place if their origins were the same. Moreover, at least three important genera (*Paraduplopnyllum, Cardiaphyllum, Assimulia*) are common to the Glass Mountains (Texas) and Southern China (Xinjiang, Guizhou) (Wu and Zhou 1982; Fedorowski, in press *a, b*). Unfortunately, data are lacking on the occurrence of those genera in the far western part of Texas. They have not been recorded either from California or from the Central Great Basin, or from other subprovinces distinguished by Stevens and Rycerski (1984). It is difficult for me to accept that parts of southern China and the Glass Mountains, now located so far inland, are accreted terranes that were originally part of a single carbonate platform located somewhere in the Paleopacific Ocean and moved to Recent positions by the subduction. As far as I know there are no data supporting such a supposition.

An approach can be made to the problem of the distribution and relationships of rugose coral faunas of the North American and Asiatic (mainly Chinese) parts of the Pacific Ocean, using papers by Wilson (1980, 1982), Sando (in press, *a, b*) Fedorowski (in press *a, b*) on the Upper Carboniferous and/or Lower Permian coral faunas of the North America, and Yu (1977, 1980), Wu and Zhou (1979, 1982), Guo (1982, 1983), Wang (1983), Wang and Yu (1983), Wang, Chen and Wu (1983), Wu (1984), and Zhang (1984) on China.

Detailed discussion of the world's distribution of Upper Carboniferous coral faunas is restricted in this paper, because this problem has recently been discussed by Fedorowski (1981) and Vassiljuk (1984). The list of the Chinese corals, published by Fedorowski (1981) should be corrected, however. Only the corals attributed to the so-called Lower Zone belong to the Upper Carboniferous. The fauna of the Upper Zone belongs to the Pseudoschwagerina Zone (= Asselian), which, since 1957, has been included into the Upper Carboniferous by Chinese geologists, following usage by Sun (1957). More details concerning the Carboniferous/Permian boundary in China are below, together with remarks on that area.

I now wish to discuss some ideas of Vassiljuk (1984). I cannot agree with the Vassiljuk's (1984:79) statement that: "Bothrophyllidae, abundant only at the beginning of the Upper Carboniferous, disappeared at the end of Kasimovian." (translated herein from Russian). Abundant representatives of that family are known to occur both in the Gshelian as well as the Asselian-Sakmarian equivalents of Vestspitsbergen (e.g. Heritsch 1929, 1939; Forbes *et al.* 1958; Fedorowski 1965, 1967; Tidten 1972), Bear Island (Fedorowski 1975), Canadian Arctic Archipelago (Harker and Thornsteinsson 1960; Bamber, *In*: Nassichuk and Davies 1975; and Nassichuk and Wilde 1977), some areas of the Cordillera (e.g. Wilson 1982), SW Texas (Ross and Ross 1962; Fedorowski, in preparation) China (e.g. Paleontological Atlases, 1974—1984; Wu and Zhou 1982), Vietnam (Fontaine 1961), and possibly also is some other areas. Without discussing the systematics of the Upper Carboniferous colonial corals and the correctness of using the name *Dibunophylloides* (Vassiljuk 1984:80) I note that Ross and Ross (1963) erroneously identified a solitary geyerophyllid coral from the Glass Mountains as *Lithostrotionella.*

Vassiljuk (1984:81) favoured placing the Carboniferous/Permian boundary at the base of the Sakmarian Stage, but her arguments, seemingly based on the results of Porfiriev (1949), Harker and Thornsteinsson (1960), Degtjarev (1973) and Rowett (1975) are in fact unsupported. The ideas of Porfiriev (1949) were corrected by Degtjarev (1973:91) and need no further discussion without new faunal data. Degtjarev wrote: "From the very beginning of the Permian (on the level of Schwagerina Horizon (or the Asselian Stage), large, solitary corals disappeared comparatively quickly and were replaced by abundant colonial corals." (translated herein from Russian). Thus, the statement of Vassiljuk (1984:81) that "both the colonial rugosa and the large solitary caniniid corals are absent in the lower part of the Asselian Stage of the Uralian-Arctic area, where only small, nondissepimentate corals occur" is in disagreement with the paper she referred to. Also Rowett (1975) did not state that colonial corals appear near the end of the Asselian. Harker and Thornsteinsson (1960) correlated the Belcher Channel Formation with the Artinskian of the USSR. The investigations on that formation by Nassichuk and Davies (1975) and Nassichuk and Wilde (1977) show, however, that in the type area it extends from approximately Middle Asselian to the Lower Artinskian, and in some other areas from the Upper Virgilian to the Upper Sakmarian. Corals identified by Bamber (1975, 1977) in appendices to both papers mentioned above show close relationships to the Ural Mts and the Svalbard Archipelago faunas, but the appearance of the massive colonial corals at the base of the Sakmarian has not been stated.

Vassiljuk (1984:81) correctly wrote that the Pueblo and Admire formations are "correlative in their lower parts with the Asselian", but this is true only if all of the Asselian is included in the Permian, because the lower contacts of both formations coincide with the base of the Wolfcampian (Dunbar *et al.* 1960). As mentioned by Vassiljuk (1984) Flügel (1965) accepted a Permian age for his coral fauna from Iraq, but he did not mention Asselian and did not specify the Carboniferous/Permian boundary either there or in Afghanistan. Heritsch (1936) and Homann (1971) did not correlate the third complex of the coral fauna of Heritsch (1936) with the lower part of the Asselian (Vassiljuk 1984:81), although Homann (1971:7) listed a large number of species as "Charakteristische Korallenvergesellschaftungen der Unteren Pseudoschwagerinenkalke (tiferes Unterperm)." He did not definitely assign that fauna to the third complex of Heritsch (1936) (see discussion below). There is also no basis for Vassiljuk's (1984:81) conclusion that "abundant, typically Permian colonial corals appeared only in the VI-th coral zone (Sakmarian)" (translated herein from Russian). On the contrary, Homann (1971) mentioned the possible appearance of some colonial corals as low as the Upper Carboniferous Triticites Zone.

One should not exclude the possibility that massive colonial rugose corals are absent from the lowermost Asselian in many regions, but several factors should be considered. Firstly, this may be an ecologically controlled event in those areas, because massive colonial corals are present at that stratigraphic level in China (see below). Secondly, even if their appearance did not coincide exactly with that of Pseudoschwagerina Zone, they appeared shortly afterward, thus offering no support for the proposed transfer of the Carboniferous/Permian boundary to the base of the Sakmarian. In addition, I can see no logical reason for assigning major biostratigraphic importance to the appearance of massive coral colonies belonging to at least three or four families (Durhaminidae, Kepingophyllidae, Lithostrotionidae, Waagenophyllidae). Each of those families has a different phylogeny, largely different area of the occurrence, and different stratigraphic level of the first appearance. Why should their common growth form have special biostratigraphic value?

The main purpose of this paper is to discuss the coral succession in the Carboniferous/Permian passage beds and in the lowermost Permian. Thus, the papers not dealing directly with that problem have been omitted.

REGIONAL FAUNAL DISTRIBUTION

THE CORDILLERA-ARCTIC-URALIAN REALM

Glass Mountains (SW Texas). — The existing controversy over placement of the Carboniferous/Permian boundary in this region results from at least three factors: 1. A complex lithic facies development, with individual sets of beds wedging out laterally, sometimes over fairly short distances, 2. Facies control over the benthic fauna, 3. Differences in the interpretation of the stratigraphic value of individual index fossils (e.g. Ross 1963, 1975; Cooper and Grant 1972; Waterhouse 1976). In this paper I follow Cooper and Grant (1972), who accepted the primary subdivision by King (1930), placing the *Uddenites*-bearing shell member of the Gaptank Formation at the base of Permian. My decision in supporting King's (1930) concept is based on the entry of a new coral fauna at this particular level. According to King (1930) his so-called Gray Limestone member or Bed 2 forms the base of the Neal Ranch Formation, but does not coincide with base of the Permian.

The rugose coral fauna of the *Uddenites*-bearing member, Gaptank Formation, of the Gray Limestone member (however placed), and the Neal

Ranch Formation, is a typical transitional fauna. Of the species described from those units (Ross and Ross 1962, 1963; Fedorowski, in press *a*, *b*), twenty eight occur in various combinations (Table 1) in this part of the stratigraphic column. Of these, only a group of species of *Lophophyllidium* show definitely Pennsylvanian affinities. The rest of the fauna is new, at

Table 1

Distribution of the rugose corals near the Carboniferous/Permian boundary in SW Texas

Species	LG	U	NR	LH	ab
Lophophyllidium compressum Jeffords	—	—			
Lophophyllidium distortum (Worthen)	—	—			
Lophophyllidium plummeri Jeffords	—	—	—		
Lophophyllidium wewokanum Jeffords	—	—	—		
Lophophyllidium westii (Beede)	—	—	—		
Lophophyllidium dunbari Moore and Jeffords	—	—	—	—	—
Lophophyllidium absitum (Jeffords)	—	—	- - -	—	—
? *Allotropiochisma* (? *A.*) *uddenitense* Fedorowski		—			
Assimulia uddenitense Fedorowski		—			
? *Bradyphyllum coagmentum* Fedorowski		—			
Durhamina uddeni (Ross and Ross)		—			
Lytvolasma aucta Fedorowski		—			
? *Yabeiphyllum rossi* Minato and Kato		—			
Allotropiochisma (*Abeophyllum*) *texanum* Fedorowski		—	—		
Allotropiochisma (*Alligia*) *flabellum* Fedorowski		—	—		
Bradyphyllum counterseptatum Fedorowski		—	—		
Bradyphyllum postwannense Fedorowski		—	—		
Monophyllum cassum Fedorowski		—	—		
? *Euryphyllum robustum* Fedorowski		—	—	- - -	—
Pseudowannerophyllum solidum (Ross and Ross)		—	—	—	—
Assimulia arta Fedorowski			—		
Diffingia valida Fedorowski			—		
Falsiamplexus elongatus Fedorowski			—		
Lophotichium rotundiseptum Fedorowski			—		
? *Paralleynia acclinis* Fedorowski			—		
Lophophyllidium skinneri Ross and Ross			—	—	
Actinophrentis columnare Fedorowski			—		—
Assimulia tergida (Ross and Ross)			—	—	—

Abbreviations:

ab — above Lenox Hills Formation
LG — Gaptank Formation, below *Uddenites*-bearing member
LH — Lenox Hills Formation
NR — Neal Ranch Formation
U — *Uddenites*-bearing member of Gaptank Formation

either the generic or the species level. The *Uddenites*-bearing member of the Gaptank Formation contains the oldest representative of *Assimulia*, which may be ancestral also for the North American *Paraduplophyllum*. The latter genus, which is very abundant in SW Texas, was first described in China from beds considered by Wu and Zhou (1982) to be Asselian. Representatives of the genera *Euryphyllum* and *Allotropiochisma*, which are also present in the *Uddenites*-bearing member of the Gaptank Formation, are slightly uncertain as index fossils. The North American species of the exclusively Permian *Euryphyllum* are questioned because they not completely agree with the original generic diagnosis (Hill 1938), *Allotropiochisma*, in turn, includes a subgenus *Abeophyllum*, one species of which is known to occur in the Upper Carboniferous of Spain (de Groot 1963: *Euryphyllum hispanicum*). Some features of the subgenus may suggest its independent status, but this was not proposed in the original description (Fedorowski, in press *a*). However, representatives of neither *Euryphyllum* nor *Allotropiochisma* has yet been described in North America from strata older than the *Uddenites*-bearing member of the Gaptank Formation.

A group of species that includes *Actinophrentis columnare, Bradyphyllum postwannense, B. counterseptatum, ?B. coagmentum, Monophyllum cassum* and *Lytvolasma aucta*, is typical only of the narrow time span represented by the *Uddenites*-bearing member of the Gaptank Formation and the Neal Ranch Formation. This species assemblage defines a good local biostratigraphic unit which includes the *Uddenites*-bearing member of the Gaptank Formation and the Neal Ranch Formation. It distinguishes fauna of these two units from the lower and, to some degree, also from the younger faunas of the area.

The *Uddenites*-bearing member of the Gaptank Formation also contains the oldest North American colonial Durhaminidae. Stevens and Rycerski (1984) did not acknowledge the identification by Minato and Kato (1965a) of *Dibunophyllum uddeni* Ross et Ross, 1962 as *Durhamina*, but there is no doubt that the specimen is a durhaminid. Also, *Heritschioides* sp. of Ross and Ross (1963), which was renamed *Yabeiphyllum rossi* by Minato and Kato (1965a) and *Dibunophyllum hessensis* Ross et Ross, 1962 (= *Durhamina*) undoubtedly belong to the family Durhaminidae. Doubt concerning the stratigraphic position of *Y. rossi* was dispelled by Cooper (oral communication), who considers locality USNM 701p to definitely belong to the *Uddenites*-bearing member of the Gaptank Formation. This is confirmed by Cooper and Grant (1972). There is still uncertainty concerning the occurrence of *Durhamina* in Japan and China, *Heritschioides* in Japan, and *Yabeiphyllum* in the USA. Stevens and Rycerski (1984:27) questioned, without any broader discussion, and identification of *Corwenia hasimotoi* Nagao and Minato (1941) and *Durhamina kitakamiensis* Minato and Kato (1965*a*) as *Durhamina*. They also stated: "*Yabeiphyllum* is reported from both Japan and Texas, but figures of the Japanese species are so poor (Minato and Kato 1965*a*), that it is not certain that the two corals actually belong to the same genus." The occurrence of the genus *Heritschioides* outside North America was questioned by Wilson (1980). The difficulty in comparison of the North American and Japanese species is mainly due to the bad state of preservation of the latter, especially that of *D. hasimotoi*. The presence of geographic barriers (fig. 1) strongly suggests that the species from both sides of the Paleopacific belong to separate genera, unless the idea of Stevens (1983) and Stevens and Rycerski (1984) concerning the "area of Pseudopavoniidae" applies to the Durhaminidae as well, which seems doubtful to me.

Arguments against acknowledging *Heritschioides* sp. of Ross and Ross (1963) as *Yabeiphyllum* are easier to articulate. The Japanese type species of that genus — *Y. hayasakai* Minato et Kato (1965) — although poorly preserved, exhibits features suggesting affinities with *Tanbaella izuruhensis* (Sakaguchi et Yamagiwa, 1958) rather than "Y." *rossi* Minato et Kato (1965). In addition, the holotype of "Y." *rossi* its distinguished by channels connecting individual corallites within the colony (Fedorowski 1980). On the basis of this character and some rather less important features, a new generic name is being proposed for this species (Fedorowski, in preparation).

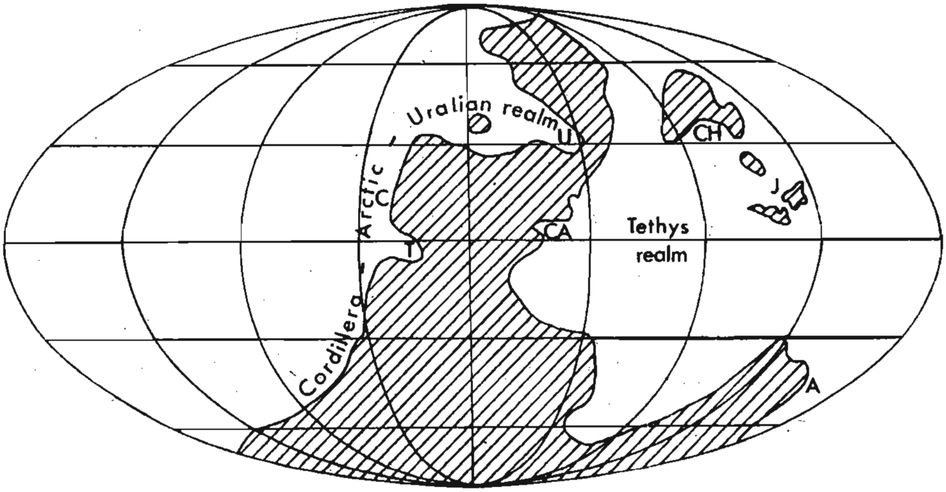

Fig. 1. The Lower Permian paleogeography and coral distribution. Paleogeographic base map, taken from Scotese *et al.* (1979) was slightly generallized. *A* — Australia, *C* — California, *CA* — Carnic Alps, *CH* — China, *J* — Japan, *T* — West Texas, *U* — Ural Mountains.

The separate generic status of the American and Asiatic colonial Durhaminidae does not preclude a natural scheme of systematic within the framework of that family, if one accepts the close relationships between the solitary Upper Carboniferous "*Dibunophyllum*" of North America, *"Cyathoclisia"* of the USSR and *Amandophyllum* of Austria, Yugoslavia and China. Most students already concluded that several, if not all, of the species concerned belong to the genus *Amandophyllum*. The independent, parallel evolution of descendents of *Amandophyllum* into a colonial growth form in the Tethys and the Cordillera-Arctic-Uralian Realm (see fig. 1) seems at least possible to me.

Also, the species described as *Neokoninckophyllum* in papers such as those by Moore and Jeffords (1945), Rowett and Sutherland (1964), Cocke (1971), Cocke and Molinary (1973) and Sando (in press, *a*), and those identified similarly in China (e.g. Yu 1980), as well as *Cardiaphyllum* Wu and Zhou (1982), may also be considered congeneric or very closely related. Their ancestral form may possibly occur near the Mississippian/Pennsylvanian boundary, i.e. at the time when the Permian realms were not yet separated. Thus, in this group of corals as well, a natural relationship of species derived from both sides of the Paleopacific is possible.

Acknowledgement of the possibility of parallel evolution in both of the above mentioned groups of corals in the Late Carboniferous and Early Permian reduces their value for intercontinental correlation. At the same time, however, it explains the presence of *Cardiaphyllum*, for example, both in Tibet, where that genus is accompanied by a coral fauna typical for the Permian of Timor Island (Wang and Yu 1982), and in SW Texas (Ross and Ross 1962, 1963; Fedorowski, in preparation), where it is accompanied by an almost totally different assemblage of corals. This also applies for the genus *Sestrophyllum*, which currently is definitely recognized only in the Donetz Basin (Fomichev 1953), in Spain (Rodriguez 1984) and in SW Texas (Fedorowski, in preparation). The specimens included in that genus in China (Wang 1978; Wang and Yu 1982) do not show its major characteristics and may belong to *Amandophyllum*. The direct communication between the Tethys and the North American seas up to the Upper Carboniferous, suggested by Rodriguez *et al.* (in press) should also be considered as an alternative. This does not concern Permian realms, however.

Three factors weigh strongly in favour of accepting *Uddenites*-bearing member of the Gaptank Formation as the beginning of the Permian phase of evolution of rugose corals, at least in the region now under discussion: the appearance in this member of genera that are important in younger, undisputed Permian rocks; the strikingly close relationship of the coral fauna of this member to that of the Neal Ranch Formation; and the clear distinction observed between the two faunas above the base of the member and those from older parts of the Gaptank Formation. This position for the base of the Permian would be in agreement with that indicated by the evolution of brachiopods (Cooper and Grant 1972; Waterhouse 1976).

Northern California. — Wilson (1982) summarized older data and described the rich coral fauna of the McCloud Limestone. According to

Wilde's (1971) zonation, which was adopted by Wilson (1982), the McCloud Limestone coral fauna is slightly younger than the Glass Mountains coral fauna, however. With the exception of *Heritschioides*, the oldest species described by Wilson (1982) are solitary forms related to the Uralo-Arctic taxa. All those solitary coral species, as well as the oldest *Heritschioides*, appeared in fusulinid Zone A of Wilde (1971), which was correlated by that author with the Gray Limestone member of the Neal Ranch Formation in the Glass Mountains and considered Lower Permian. The rugose coral fauna of northern California differs from that in the Glass Mountains in exhibiting an overwhelming preponderance of colonial species, including cerioid and plocoid forms, and an absence of *Paraduplophyllum* and *Assimulia*. This may have resulted from facies control, or may indicate the presence of a distinct zoogeographic province or subprovince. However, Stevens and Rycerski (1984, fig. 4), possibly following Yancey (1975, 1976), Coney *et al.* (1980), or others, accepted the thesis that the McCloud Limestone is a terrane developed west of the Cordillera on the Paleopacific Ocean. Wilson (1982:9), who did not acknowledge such a reconstruction, stated: "The Tethyan Coral Province of Asia is not present in North America." Indeed, it is not possible to check identifications of the suspected Tethyan corals cited by Stevens (1983) and Stevens and Rycerski (1984), because their fauna has not yet been published. Until the ideas of Stevens and Rycerski (1984) are fully documented, I prefer to adopt Wilson's (1982) view that the Asian Tethyan coral province is not represented in the Permian of North America. This view is further supported by the fact that the species of *Yatsengia* described by Wilson (1982) differ distinctly from the Asiatic type species of that genus, but instead, closely resemble the North American Durhaminidae. Thus, the coral fauna of the McCloud Limestone has no close Asiatic affinities. On the contrary, it shows fairly close relationships with the coral faunas of other parts of the Cordillera, Alaska, and the Canadian Arctic Archipelago. This has already been pointed out by Wilson (1982:8,9). The solitary corals, not mentioned by the latter author, strongly emphasized those relationships, being readily comparable with the species described by Salter (1855), Harker and Thornsteinsson (1960), and Rowett (1969, 1975) from the Canadian Arctic Archipelago and Alaska. These relationships can easily be extended towards the east onto the Svalbard Archipelago (Heritsch 1929, 1939; Fedorowski 1965, 1967, 1975; Birkenmajer and Fedorowski 1980; Tidten, 1972), Ural Mountains (Stuckenberg 1895; Dobroljubova 1936*a*, *b*; Soshkina, Dobroljubova and Porfiriev 1941), and possibly also the Moscow Basin (Dobroljubova 1937, 1941). I offer no opinion here concerning the accuracy of the generic identifications made by Wilson (1982). Such genera as *Aulophyllum*, *Clisiophyllum* or *Heterocaninia* are certainly not present in the coral fauna described by that author, but the occurrence of a genuine *Gshelia* may be of special value for both biostratigraphy and paleogeography.

The coral fauna in the rest of the Cordillera, Alaska and the Canadian Arctic Archipelago is omitted from this discussion, because either the stratigraphic positions of corals in those areas are not established quite well enough to be used for distinguishing the Carboniferous/Permian boundary, or the faunas occur too high in the Permian to be relevant, or only lists of species are available.

The Ural Mountains. — The Gshelian/Asselian rugose coral faunas of the Ural Mountains were described long ago (Stuckenberg 1895; Dobroljubova 1936*a*, *b*; Soshkina, Dobroljubova and Porfiriev 1941) and have not been revised since. This presents many difficulties and controversies concerning their correct location in the stratigraphic column, Because massive colonial rugose corals are absent from the Upper Carboniferous deposits of the Ural Mountains (Degtjarev 1973), the appearance of *Kleopatrina*, *Protowentzelella*, *Protolonsdaleiastraea*, *Stylastraea* and *Thysanophyllum* must be considered to be stratigraphically important. Unfortunately, it is not quite certain wheter the appearance of those genera can be equated with the lower limit of the Pseudoschwagerina Zone, although their dominance seems obvious at least in the higher part of this zone (Degtjarev 1973: tables). The dissepimented, solitary rugosans, especially *Timania* and large "*Caninia*" or "*Caninophyllum*", were reported from the Upper Carboniferous (Smirnov *et al.* 1978) and also from strata containing "*Schwagerina*" (Dobroljubova 1936a). Nevertheless, when thoroughly investigated, this is a promising group for biostratigraphy and for correlation between faunal realms. Thus, a new systematic study of the Upper Carboniferous and Lower Permian corals of the Ural Mountains, verified by fusulinid data, is badly needed. The most recent discussion by Degtjarev (1973) and Vassiljuk (1984) is mentioned above.

The Svalbard Archipelago. — A rugose coral fauna closely comparable to that of the Ural Mountains extends northwest to Vestspitsbergen. It mainly includes corals from the upper Treskelodden beds, and the "Mid-" and "Upper Wordiekammen Limestone" of Vestspitsbergen (Forbes, Harland and Hughes 1958; Fedorowski 1965, 1967; Birkenmajer and Fedorowski 1980). Unfortunately, nowhere in Vestspitsbergen are the coral-bearing deposits of the Carboniferous/Permian boundary definitely identified. This can be clearly seen in the most frequently cited or the most recent papers (Forbes *et al.* 1958; Forbes 1960; Cutbill and Challinor 1965; Birkenmajer 1964, 1981). In the vicinity of the Hornsund area there is an obvious transgressive unconformity near that boundary. An absence of fusulinids, conodonts and ammonoids prevents accurate dating of that transgression. The coral fauna considered Artinskian by Fedorowski (1965, 1967) was suggested by Birkenmajer and Fedorowski (1980) to be older. It is most probably comparable to the Asselian coral fauna of the Ural Mountains, which is characterised by a predominance of the massive coral colonies.

Lack of detailed data from the Ural Mountains (see above) makes closer assignment and comparison impossible. Steel and Worsley (1984; fig. 13) thought that the area of the Treskelen Peninsula (Hornsund) was part of the Sakmarian landmass. This is in disagreement with my study in that area (Fedorowski 1982) and is not accepted in this paper.

A coral fauna very similar to that in the upper Treskelodden beds, is known to occur in the Hambergfjellet Formation on Bear Island (Fedorowski, unpublished). It disconformably overlies the "Fusulina Limestone" i.e., the Kapp Dunér Formation (Worsley and Edwards 1976). There are no more precise data concerning the latter formation. Worsley and Edwards (1976) considered it to be more or less equivalent of Orenburgian, but they correlated upper 2/3 of that Stage with Permian. The coral fauna of the Kapp Dunér Formation differs slightly from that of the Hambergfjellet Formation, but contains colonial rugose corals (Fedorowski, unpublished) that may suggest an Early Permian (Asselian) age, only slightly younger than that of the Hambergfjellet Formation. The suggestion by Cutbill and Challinor (1965) and Birkenmajer (1981) that the "Fusulina Limestone" extends up to Lower Asselian may thus be correct, but it should be placed below the upper Treskelodden beds of the Hornsund area in the stratigraphic column.

Descriptions of Upper Carboniferous and Permian corals from the inner part of the Billefjorden area (Central Vestspitsbergen) either lack definite stratigraphic dating (Heritsch 1929, 1939; Padget 1954; Tidten 1972) or consist only of faunal lists (Forbes *et al.* 1958). Nevertheless the existing data is useful to some extent. The total faunal assemblage, including the rugose corals, indicates that at least the Cadetfjellet member of the Nordenskjöldbreen Formation belongs to the Upper (Uppermost?) Carboniferous, as indicated by Cutbill and Challinor (1965). The Cadefjellet coral fauna, which was briefly checked by me in the Sdgwick Museum, Cambridge, includes *Gshelia*, *Bothrophyllum*, and probably also *Arctophyllum*. Massive colonial rugose corals are absent, but *Heintzella* and *Fomichevella* occur. Continuous sedimentation in across the Carboniferous/Permian boundary is suggested in that region by the fact that the entire succession of strata has been assigned to a single formation. Also, none of the authors dealing with the so-called "Wordiekammen Limestone" noted any break in sedimentation within the sequence. Unfortunately, there are no data concerning the order of appearance of the coral species. Thus, the whole coral fauna of the Cadefjellet member, and possibly also of the lower part of the Tyrrelfjellet member (up to the first appearance of *Pseudoschwagerina*) should be considered as an Upper Carboniferous fauna, and an Asselian age should be assigned to the fauna of the overlying calcareous part of the Tyrrelfjellet member. This part of the sequence (= upper "Mid-" and "Upper Wordiekammen Limestone") up to the so-called "Limestone B" contain *Pseudoschwagerina*, whereas *Parafusulina* first occurs in

"Limestone B" (Forbes *et al.* 1958). Thus, the whole coral assemblage of the former "Upper Wordiekammen Limestone" can be roughly correlated with the coral-bearing part of the upper Treskelodden beds of the Hornsund area, and possibly also with the Hambergfjellet Formation of Bear Island. The gap in sequence between the Kapp Dunér and the latter formation, present on Bear Island, would be absent in the Central Vestspitsbergen, but present in the Hornsund area, if this correlation is correct.

In spite of the different names used, the massive colonial rugose coral fauna is the same in all three areas discussed. *Kleopatrina*, *Stylastraea* and *Thysanophyllum* predominate, but *Protowentzelella* and *Protolonsdaleiastraea* are also present. There are also several species in common.

The Moscow Basin. — As shown by Dobroljubova (1948), the Asselian coral fauna does not differ significantly from that of the Daixina sokensis Zone. Only the absence of the rugosans with massive colonies draws attention. This, and the domination of geyerophyllids (*Amygdalophylloides* and *Koninckocarinia*) causes great difficulty in correlating the Moscow Basin fauna with that of the Ural Mountains. Perhaps the coral fauna of the local Moscow Basin sea was partly or completely isolated from that of the Cordillera-Arctic-Uralian Realm. Its connection with the Tethys Realm is not indicated either.

THE TETHYS REALM

China. — In spite of the large territory and the variety of geotectonic and facies development in China, the rugose coral faunas of the Carboniferous/Permian passage strata from all parts of that country are discussed together in this paper. This is done because the stratigraphy and coral faunas of some areas are not adequately known. Following the usage of Sun (1957), the Carboniferous/Permian boundary accepted in China has been placed near the base of the Sakmarian of the USSR, the Leonardian of North America, and the Trogkofel in the Carnic Alps, "but this is a matter of definition, not an alternative correlation" as was pointed out by Waterhouse (1976:64), who commented on the older literature data.

A new approach to the problem has been made possible by the appearance of more recent publications. These include a series of paleontological atlases for individual regions of China, issued since 1974, fairly numerous paleontological descriptions of the Upper Carboniferous and Lower Permian coral faunas (e.g. Yu 1977, 1980; Wu and Zhang 1979; Wu and Zhou 1982; Wu and Kong 1984; Guo 1982, 1983; Wang and Lju 1982; Wang and Yu 1982; Wang, Chen and Wu 1983), and stratigraphic papers based on both corals and fusulinids (Wang 1983; Wu 1984), fusulinids alone (Zhang 1984) or on broader faunal assemblages (Hou *et al.* 1982). The three groups of authors of stratigraphic papers mentioned above have adopted three different approaches to the problem of the Carboniferous/Permian boundary. The first group proposed that the base of the Permian be lowered to the base of the Pseudoschwagerina Zone, so that it corresponds to the boundary that is most commonly used, if not generally accepted, throughout the world. In China, the boundary between the Carboniferous and Permian systems would then occur in the middle of the Maping Formation (or the Maping Stage of authors), which seems unacceptable for at least some Chinese stratigraphers. The subdivision and boundary proposed by the third group of authors mentioned above follow more or less exactly those introduced by Sun (1957) and need no further discussion. Zhang (1984) demonstrated quite a new approach to the problem. According to him the Carboniferous/Permian boundary should be lowered to the base of the Mapingian Stage, with the international equivalents for its lower part as follows: Kasimovian to Orenburgian in the USSR, Missourian and Virgilian in North America, and the Triticites Zone of Japan and the Carnic Alps. Zhang (1984) also introduced a correlation table of southern Chinese strata, which is useful for foreign students, although his idea concerning lower boundary for Permian is unacceptable to me.

Wu (1984) and Zhang (1984) included tables and/or more detailed descriptions of the strata adjacent to the Carboniferous/Permian boundary. Unfortunately, the interpretations of those authors are in such disagreement that automatic acceptance of the name "Pseudoschwagerina Zone" for the different Chinese areas seems impossible. I have accepted the interpretation of Wu (1984), because it is best documented, and have consequently been able to accept her considerations regarding the coral fauna near the Carboniferous/Permian boundary. The appearance of massive, plocoid, colonial corals near the lower boundary of the Mapingian and the presence of numerous solitary corals of clearly Carboniferous and interregional character at this level are of special significance. Without commenting in detail on the ideas of Wu (1984), I wish only to suggest that her acceptance of *Ivanovia* as the ancestral genus for Kepingophyllidae was not documented and may have been based on the fact that *Ivanovia* is the only plocoid genus present in the lower part of the Upper Carboniferous. The true *Ivanovia* from the Moscow and the Donetz Basins does not show any features in common with Kepingophyllidae.

The colonial rugose corals in China are either endemic or are exclusively characteristic of the Tethys Realm, but the assemblage of solitary, dissepimentate genera, as well as the Geyerophyllidae, which are abundant and diversified in China, may allow inter-regional correlations when precisely studied. It appears that *Paraduplophyllum* may be an important genus for correlation between realms. It was described for the first time from the Asselian of China (Wu and Zhou, 1982) and is also very abundant in the upper part of the Wolfcampian of SW Texas (Fedorowski, in press, *a*). Its fairly close similarity to *Kabakovitchiella* Weyer (1972) is a problem, however. The latter genus is known, so far, only from Permian strata of Timor and the Carnic Alps, but "*Duplophyllum*" from the Kasimovian Stage of Cantabria (Northern Spain), described by Rodriguez (1984), shows several similarities both to *Kabakovitchiella* and to "*Duplophyllum*" of Schouppé and Stacul (1959), recently renamed by Fedorowski (in press, c). Unfortunately, the original descriptions of *Kabakovitchiella* were based on incomplete specimens (Fedorowski in press, c) and its systematic position is uncertain. After a brief examination of originals of the Spanish "*Duplophyllum*" it seems most likely to me that they are ancestral both for *Kabakovitchiella* and "*Duplophyllum*" of Schouppé and Stacul (1959). This problem await more detailed study of the Spanish material. Fedorowski (in press, a) suggested that *Kabokovitchiella* and *Paraduplophyllum* are independent genera of different origin. Further study of the Spanish corals may show that this interpretation is wrong, and that the generic name *Paraduplophyllum* is invalid. The corals that would then be groupped under the name *Kabakovitchiella*, however, would still be important for inter-realm paleogeographic studies.

A preliminary assessment indicates that the most important characteristics of the Chinese coral faunas of the Carboniferous/Permian boundary interval are: great diversity and abundance of Waagenophyllidae; presence of endemic cerioid and plocoid rugose corals both in the Upper Carboniferous and Lower Permian at least in some areas; and predominance over the "*Cyathaxonia*-fauna" of the so-called "*Caninia*--*Clisiophyllum* Fauna" (with abundant Geyerophyllidae) and "Reef Coral Fauna" in the Pseudoschwagerina Zone and above it (faunal names from Hill, 1938—1941). It must be pointed out, however, that the Chinese coral fauna must be analysed so that epicratonic and geosynclinal occurrences can be differentiated from occurrence in possibly allochtonous terranes. Such an analysis is beyond the scope of the present paper.

Japan. — Corals are probably absent from the Upper Carboniferous Triticites Zone of Japan, although Minato and Kato (1977) noted a possible occurrence of *Yabeiphyllum* and ? *Yokoyamaella* either in this or in the overlying Zone. The Lower Permian strata of the Pseudoschwagerina Zone are most completely developed in the Kitakami Mountains. There they begin with the basal conglomerate and rest unconformably on various older deposits (Minato and Kato 1978) *Lophocarinophyllum seutonii* (Minato 1955), reported to be the most common fossil in the lower and middle part of the Kawaguchi Stage, is there accompanied by *Wentzelella*. Corals become more diversified only in the upper part of that stage (Minato and Kato 1978). Minato (1975) in his summary of coral studies in Japan, listed 14 species from the Pseudoschwagerina Zone. Waagenophyllidae and Durhaminidae predominate, but *Geyerophyllum* and some nondissepimentate corals also occur. Minato (1975) and Minato and Kato (1977) pointed out the regional diversity of the rugose coral faunas, but nevertheless considered them to be tethyan in the character.

The Carnic Alps. — The well-established stratigraphy based on Foraminifera (Kahler 1974; Kahler and Kahler 1941, 1980), the litho-facies characteristics (Homann 1969) and the algal build-ups (Flügel 1981) of the Lower Permian of the Carnic Alps make the area one of the most important for considerations of coral paleogeography. However, most of the existing descriptions of the coral fauna itself (Heritsch 1933, 1936; Felser 1937; Gräf and Ramovš 1965; Homann 1971; Holzer and Ramovš 1979) need revision.

The Lowermost Permian Rattendorfer Stage is considered to be fully correlative with the Asselian of the USSR (Flügel 1981, Table 1). It contains three formations, each corresponding to one of the sequential fusulinid zones: Lower Pseudoschwagerina Formation (= Occidentoschwagerina alpina Zone), Grenzland Formation (= Schwagerina moelleri Zone), and Upper Pseudoschwagerina Formation (= Schwagerina glomerosa Zone). The oldest of these formations is in turn subdivided into four clastic-carbonate cycles, with the coral fauna occurring in the carbonates (Homann 1969). Homann (1971) revised the rugose coral species introduced by Heritsch (1933, 1936) and Felser (1937). Unfortunately, the quality of the systematic identifications by Homann (1971), as well as the material illustrated by him, preclude definite acceptance of his data. The coral fauna of that important region needs a thorough revision on the basis of more complete material. Nevertheless, one can still conclude that the most diversified coral fauna occurs in the lower three cycles of the Lower Pseudoschwagerina Formation, which are developed on the inner shelf zone (Homann 1969; Flügel 1981). The occurrence of *Wentzelophyllum* could have had considerable significance for regional correlation, but according to Homann (1971:140) the Alpine species of that genus are not restricted to the Permian, but first appear in the Upper Carboniferous. The same is true for "*Durhamina*" *ampfereri* Heritsch, 1936, all species of *Carinthiaphyllum*, and *Lonsdaleoides boswelli* Heritsch, 1936. A possible occurrence of *Yokoyamaella* in the Triticites Zone of Japan (Minato and Kato 1977) has also made that taxon less useful for the lowermost Permian stratigraphy, at least on the generic level. The appearance of *Wentzelophyllum* and *Yokoyamaella* in the Uppermost Carboniferous of the Carnic Alps may have considerable value for determination of the regions of origin for some Waagenophyllidae, however.

The Lower Permian Rattendorfer coral fauna in the Carnic Alps and Karawanken is remarkable for two main reasons: 1. It is the most westerly occurrence of the Waagenophyllidae, which are represented by *Wentzelophyllum arminiae*, *W. felseri*, *Yokoyamaella carinthiaca* and *Y. stillei*; 2. It contains an abundance and diversity of Geyerophyllidae, especially *Carinthiaphyllum*.

CONCLUSIONS

1. Two distinct rugose coral faunal realms can be distinguished in the Lower Permian: the Cordillera-Arctic-Uralian Realm, and the Tethys Realm (fig. 1). Some provinces within those realms (e.g., the *Kepingophyllum* Province in China and the SW Texas province in the USA) are more or less endemic. There are also considerable differences between the faunas of the Cordillera and those of the Ural Mountains and Spitsbergen. The geographic position of Australia and Timor, reconstructed by Scotese *et al.* (1979) is in contradiction with the coral evidence. One can hardly, if at all, accept the occurrence of the so a rich coral fauna as that of Timor so close to the South Pole.

2. Rugose corals may serve as a supplementary group of fossils for establishing the lower limit of the Permian System in some areas. The beginning of the Permian phase of the evolution of rugosans coincides mainly with the appearance of the oldest Permian brachiopods and *Pseudoschwagerina*. It is stricking, however, that some typically Permian rugose coral taxa appeared earlier than the oldest Permian fusulinids (Japan, Carnic Alps), or that the rugosans seem to reach their Permian phase of evolution earlier than ammonoids and perhaps also some fusulinids (SW Texas).

3. Correlations based on corals are possible within realms, but only *Paraduplophyllum* has some restricted value for correlation between realms. Geyerophyllidae may be important for that purpose in the future.

4. Uppermost Carboniferous deposits, except for the *Kepingophyllum* Province in China, do not contain rugosans with massive colonies. The level of appearance of such corals near the Permian boundary may vary from one region to another and cannot be used as a general stratigraphic marker. It may have some value, however, when considered separately by families and for individual regions.

5. Parallel evolution of some families (e.g. Durhaminidae, Geyerophyllidae, Bothrophyllidae, and some nondissepimentate families), derived from common early Upper Carboniferous ancestors may have taken place independently in the Tethys Realm and Cordillera-Arctic-Uralian Realm. i.e. on both margins of the Paleopacific (fig. 1).

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JERZY FEDOROWSKI

FAUNY KORALOWCÓW RUGOSA Z POGRANICZA KARBONU I PERMU

Streszczenie

Dokonano krytycznego przeglądu najnowszej i starszej literatury dotyczącej zagadnienia stratygrafii i faun koralowych warstw przejściowych od karbonu do permu, ze szczególnym uwzględnieniem poziomu *Pseudoschwagerina*. Wyróżniono dwa królestwa: królestwo Kordylierów, Arktyki i Uralu oraz królestwo Tetydy. Omówiono fauny koralowe poziomu *Pseudoschwagerina* najważniejszych regionów wchodzących w skład obydwu królestw. Stwierdzono pewne znaczenie koralowców Rugosa dla określenia dolnej granicy permu, a także stratygraficznych korelacji w obrębie królestw. Korelacja pomiędzy królestwami jest praktycznie niemożliwa. Wysunięto tezę, że przynajmniej niektóre rodziny Rugosa, pochodzące od wspólnych przodków z początków górnego karbonu (w podziale dwudzielnym), rozwijały się równolegle do siebie w obydwu królestwach.